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THE APOLLO STANDARD INITIATOR

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(NASA TMX 50602)

CONCEPT DEVELOPMENT

Pyrotechnic devices and systems have been selected to perform many of the most critical functions in the Apollo spacecraft system because of their high power-to-weight ratio, their small size and their high reliability. These factors combine to permit the achievement of the extremely high reliability apportioned to the flight safety functions.

The philosophy adapted for the Apollo spacecraft is that the crew shall have the capability of abort during any phase of the flight mission. Since the electro-explosive initiator is the heart, and probably the most critical component of any electrically actuated pyrotechnic system, the reliability apportioned to the initiator has been established at 99.9 percent with a confidence level of 90 percent. To demonstrate this reliability for any initiator requires 2,303 firings without failure.

Obviously, if a number of "makes and models" were used in the spacecraft, the reliability demonstration of all of them would be prohibitive from the standpoints of both time and cost. If, on the other hand, a single initiator could be used, this demonstration could be more easily attained. By early 1964, over 4,000 initiators will have been fired in the Apollo program.

At the time the Standard Initiator concept was originally established for Project Apollo, it was desired to obtain a single device capable of performing three basic functions, namely, (1) initiate propellent charges, (2) initiate high explosive charges, and (3) operate directly small hot-gas-operated devices. It soon became apparent that while such a device might be within the state of the art, the time and cost of development were largely indeterminate. It was therefore necessary to modify the original concept and to use a conversion module for the detonation of high explosives. The Apollo spacecraft, therefore, uses a standard initiator which, by itself, performs two of the desired functions and is assembled into a standard detonator cartridge (Figure 1) to perform the third function.

SPACECRAFT APPLICATIONS

As an independent pressure cartridge the initiator directly operates a few small devices such as explosive switches in the electrical power distribution system and explosive valves in the command module reaction control system. The applications are relatively few however, and for most applications in the spacecraft the initiator is factory assembled (welded) into a family of general and special purpose cartridges (Figure 2).

Pressure Cartridges (Special Purpose)

For applications where a high pressure and/or a large volume of high pressure propellent gas is required, the standard initiator is assembled (welded) into appropriately sized pressure cartridges. At present, three such cartridges are required:

Type I: Drogue parachute mortar

Type II: Main parachute pilot mortar

Type III: Forward heat shield separation system (a thruster system).

The output of these three cartridges ranges up to 18,000 psi in a 10 cc volume.

Igniter Cartridge (General Purpose)

This cartridge converts the output of the initiator to one suitable for ignition of pyrogen units and pellet baskets of rocket motors. The output of this cartridge is 600 calories (minimum) and 2,100 psi in a 10 cc volume. The cartridge replaces the originally used EBW initiators to ignite the three rocket motors in the launch escape system. The physical dimensions of the cartridge were selected to retrofit directly into existing rocket hardware. In the conversion from EBW to hot-wire ignition there has been no discernable change in the motor ignition characteristics.

Detonator Cartridge (General Purpose)

This cartridge converts the initiator output to one having characteristics suitable for reliable detonation of high explosive charges. Like the initiator, the detonator cartridge is both field-assembled into explosive systems and factory-assembled (welded) into specialized cartridges. As an independent unit the detonator cartridge is used with various linear shaped charge systems such as that used for separating the service module from the adapter after insertion of the spacecraft into trans-lunar trajectory. The detonator, welded into specialized cartridges, is used for such applications as the launch escape tower separation bolt.

Overall Usage in the Spacecraft.

Figure 3 shows the presently defined applications of the initiator and the initiator-based cartridges. These applications do not include any of those for the Lunar Excursion Module (LEM) since these have not yet been defined, however, all pyrotechnic functions in the LEM will be initiated by the Apollo Standard Initiator. Based on the experience of Projects Mercury and Gemini it appears very likely that the total number of initiators shown in Figure 3 will at least double during the course of development of the Apollo spacecraft system.

GENERAL DESIGN CONSIDERATIONS

Size and Weight

As for all spacecraft devices, the size and weight of the initiator are extremely important. By itself the weight of the initiator is almost insignificant, however, the aggregate weight of all initiators carried in the spacecraft can be important. Every Apollo component is carefully analyzed to determine if even ounces can be eliminated, for 1 pound added to the spacecraft, requires carrying an additional 1.37 pounds of propellant for the spacecraft propulsion system. The size of the initiator is also critical; where it is not practicable or possible to provide redundant pyrotechnic devices the next best approach is to provide redundant initiators on each device. If the size of the initiator is not sufficiently small then the device may have to be enlarged.

Bridgewire Redundancy

Based on the experience of Project Mercury it is very probable that additional pyrotechnic functions will be added and the location and configuration of now defined devices will be altered during the course of Project Apollo. It may become necessary to provide for contingencies wherein only a single initiator can be used in a device and where redundancy of devices is impossible. In such instances the redundancy of the electro-explosive interface in the initiator is essential, even though it would require routing of the firing leads from both power sources through a single initiator connector. To provide for such contingencies, a dual bridgewire system (four pins) was selected for the Standard Initiator.

Environmental Conditions

The environmental conditions experienced by the initiators in the spacecraft will vary according to their location and the degree of protection afforded by the spacecraft structure. No specific degree of protection can be assumed since all locations of the initiator are not yet defined. It is therefore imperative to establish "worst conditions" as the environmental requirements. The environments selected as the operating, or mission, environments for the initiator are, essentially, those anticipated for equipment mounted on the external surface of a lunar mission spacecraft with minimum special protection. The more rigourous environments are outlined in Figure 4.

Naturally, the device must also meet the normal environmental requirements and those associated with storage, handling, and shipping.

Fool-proofing

An extremely important consideration in the design of initiators, in fact in the design of all pyrotechnic devices, is the prevention of misinstallation of the device and misconnection of firing leads. This problem frequently receives all too little consideration in the design of devices and systems. It must be assumed that if it is physically possible to install the device in the wrong place, or to connect the wrong firing leads, somewhere or sometime this will be done.

As a result of previous spacecraft experience the Apollo philosophy is to design every pyrotechnic device and system so that a person with very little training can install the devices properly (while wearing mittens, if possible) and, also, to design it so that he cannot install it elsewhere or connect the wrong firing leads.

Note (Figure 2) that the output ends of all threaded devices differ in size and thread with one exception, that of the detonator and igniter cartridge. This situation was unintentional and is being corrected. Since this example illustrates a dangerous trap for the unwary, an explanation is appropriate. At first, each systems design group had responsibility for procuring the pyrotechnic devices to be used in its systems; under these circumstances, the coordination and configuration control of the pyrotechnics was very difficult. The propulsion group procured EBW initiators for the motors in the launch system and the mechanical devices group procured the detonators for separation systems - and both groups specified 9/16-18UNF threads. When motor ignition was changed to hot-wire it was desired for the new igniter cartridge to retrofit existing rocket motor hardware in order to prevent delay of the motor firing program. When it was discovered that the two devices were interchangeable it was decided that the points of installation of the igniter and detonator cartridges were sufficiently separated to reduce the possibility of misinstallation to an acceptable minimum, especially since the physical configuration of the two devices differed from each other. While this was acceptable as an interim solution, the thread size of the igniter cartridge is being changed for spacecraft hardware.

Two positive actions have been taken by the prime contractor to preclude similar situations from developing in the future, namely, (1) consolidation of the responsibility for all pyrotechnic devices and systems (except rocket motors) under a central "Ordnance Systems" group reporting to the Manager of Structures Design, and (2) establishment of formal configuration control for all pyrotechnics within the Ordnance Systems group.

The prevention of connecting the wrong firing leads to a pyrotechnic device is another source of concern to the Apollo Spacecraft Project Office. An obvious solution to such problems is, of course, the indexing, or clocking, of the electrical connectors. Indexing low density items, however, introduces logistics and cost problems and, in effect, converts general purpose to special purpose items. The igniter cartridge is a low density item which will illustrate the problem and its solution.

In the launch escape system of the Apollo spacecraft, two rocket motors are mounted so that the installation points of the igniter cartridges are only 8 inches apart (Figure 5). In this situation it is physically possible for the four firing leads to be connected in a number of combinations resulting in one of the following at abort initiation:

1. Launch escape motor fires (normal, desired action).
2. Tower jettison motor fires (catastrophic failure because of insufficient thrust to lift the command module from the service module).
3. Both motors fire (catastrophic failure because the capability to jettison the tower and release the parachutes has been lost).

Initiator connector indexing could solve this problem, however it would introduce logistics problems since only six igniter cartridges are required per spacecraft, using the principle of commonality. Specializing the initiators for these cartridges during initiator manufacture would aggravate the logistics problem. It may be necessary to accept this solution because of the importance of the functions involved, however, the proposed solution outlined below seems to be acceptable from both safety and logistics aspects and is being considered.

Post-manufacturing System of Indexing

As indicated in Figure 6a, the initiator body (electrical end) can be manufactured with a number of undercut indexing slots, e.g., of trapezoidal cross-section, so that keys, either flush with the inner surface (Figure 6b) or protruding inwardly (Figure 6c), can be fitted into all slots except one.

The keys and keyways can be of such relative size that any key can be withdrawn by a special tool, but not without the tool. The resulting configuration (Figure 6d) is that of the standard initiator. At this point, the initiator is a common item and can be assembled into any device.

The initiator can then be assembled into detonator and igniter cartridges. The one o'clock key is withdrawn from the detonator assemblies and the two o'clock key from the igniter assemblies (Figures 6e and 6f). A gage is used to insure that the proper keys have been withdrawn. Similarly, all pyrotechnic cartridges can be indexed as indicated in Figure 7a; when detonators are assembled into special cartridges the connector can be further indexed (Figure 7b).

Returning now to the specific problem of igniter cartridges, since commonality in the manufacture of initiators is achieved, the major logistics problem has been solved. Igniter cartridges received at any launch site (for example, Cape Canaveral) are all indexed 12-2 and are interchangeable between the three motors. When a flight kit is assembled for a specific spacecraft any six cartridges (plus spares) can be withdrawn from storage. The six flight articles can be indexed at this time to convert them for specific motors as shown in Figure 8 and the spares left as common items to be indexed as may be required later.

The indexing technique explained above does not depend on a twelve slot system; it is readily adaptable to any current indexing or polarizing systems such as the Bendix PT series adopted for the Apollo spacecraft.

Once the connectors are indexed for specific motors it is essential that one of the igniter cartridges be converted to a different thread size to insure that, for example, the cartridge indexed for the tower jettison motor cannot be installed in the launch escape motor. If the mating hole in the launch escape motor is slightly larger than that in the tower jettison motor, the common ignition cartridge can be adapted to fit this hole. To adapt the cartridge, a threaded adapter can be installed on the appropriate cartridge at the time the connector is indexed; with both ends of the cartridges now indexed, fool-proofing can be achieved. Indexing and installation of adapters can, of course, be performed at the cartridge vendor's facility as well as at the launch site. This technique of indexing is now being studied for application to all Apollo spacecraft pyrotechnics.

Although the foregoing has departed somewhat from the specific subject of initiators the importance of fool-proofing <u>both</u> ends of all pyrotechnic devices justifies this rather lengthy discussion.

Shorted Mating Electrical Connector

From the previous experience on Project Mercury, shorting springs, clips and other devices of similar nature are considered inadequate from the standpoints of safety in handling and protection of the initiator pins. Shorted, mating electrical connectors will be used on the Apollo Standard Initiator. It may be desirable, when using indexed connectors, to provide shaped, color coded and inscribed caps for the shorted connectors to facilitate identification of the specialized devices.

INITIATOR DESCRIPTION

Because of its developmental status the internal configuration of the initiator will not be described at this time; this description will be confined to a few of the salient features.

The initiator specification control drawing is shown in Figure 9. The body size has been minimized consistent with other requirements. The washer is used to weld the initiator into other assemblies and may be either integral with the initiator body or welded thereto. Provision is made for the use of an O-ring in the field assembly of the initiator to other devices. A goal of 60,000 psi internal pressure capability has been established since some of the Apollo pressure devices operate at over 18,000 psi at the present time.

The initiator will meet the Atlantic Missile Range no-fire requirement of 1 ampere and 1 watt for 5 minutes (at 165° F) and has an all-fire current of 3.5 amperes. The bridgewire system consists of two firing circuits (four pins), each with a single bridgewire of 1.0± 0.1 ohms resistance welded to the pins and flush against the ceramic header.

RELIABILITY ASPECTS OF THE STANDARD INITIATOR

The Apollo Standard Initiator is presently being developed by two sources to a performance specification. These two competitive designs are both being used in the development of the various spacecraft systems and both will undergo qualification and extensive other evaluation tests. When sufficient data are available, one of the designs will be selected as the spacecraft design. A design, manufacturing and quality assurance specification will probably be written around the selected design to assure identity of all production items.

Since large numbers of initiators are being fired in supporting the development and qualification of the various pyrotechnic devices and systems for the spacecraft, design deficiencies will be rapidly discovered. Further, analysis of the performance of the two initiators in these development programs will assist in the evaluation of the competitive designs. Since the performance and external configuration of the two initiators are identical it is also possible to exchange available initiators from one system development program to another as required.

Other advantages also accrue through standardization. The Apollo Spacecraft Project Office considers the electro-explosive interface to be the most critical part of any pyrotechnic device. Because this interface is identical on all initiators the firing of the initiator in one device can provide data which can be directly related to firings in other devices thereby building confidence in the interface and in both devices at the same time. The use of a standard "header" was considered but was discarded in favor of the complete standardized unit because of the capability of performing lot acceptance firing tests on the initiators prior to their installation in cartridges and other pyrotechnic devices. Of course, in either the standardized header or complete item concepts, a failure in one device reflects unfavorably on the reliability of other devices. With the standard initiator there is a bright side to the picture even in this case, for subsequent firings in a number of devices will rebuild confidence quite rapidly.

One technique that can be used to build confidence in the reliability of a specific pyrotechnic device is to procure all devices for qualification, reliability assurance, device and systems tests, flight tests, and operational flights from a single lot. The various lot acceptance and systems tests preceding the first flight will consume a large percentage of the devices; and this percentage (of devices fired) will increase with each succeeding flight until the last one, during which the last of the lot will be fired. In effect, this technique results in an extremely large sample size for lot acceptance testing. This technique is being used on Project Gemini and would probably be beneficial for many projects having a relatively short life, one within the normal storage life of pyrotechnic devices.

Project Apollo, because of its extended life expectancy, cannot adopt this technique in its entirety although a modification of the technique can be used. It is feasible to procure all initiators to be used on a given flight from the same lot and thereby enhance the reliability of the most critical area - the electro-explosive interface. Figure 10 illustrates the use of this single-lot technique for a single flight of the Apollo spacecraft (less the LEM) - for example, in an extended orbital mission. The first column shows the numbers of the various devices required for flight, the second column an arbitrary but realistic and experience-based number of spares, and the third column the number of devices expected to be fired by the launch facility in preflight tests; the total of these columns is the number of devices required at the launch site to support a single mission. Similarly, the next group of columns indicates the numbers of devices for lot acceptance tests, verification tests (if desired), and the total number of devices which must be manufactured. Assuming that each device incorporates one initiator, the total number of initiators are indicated in the next column. Again lot acceptance and verification test quantities are indicated, resulting in a minimum lot size of 414 initiators to support the single mission.

Now, working from right to left and considering only the lot acceptance and launch activity tests in which initiators are used, a total of 238, or 67.6 percent of the manufactured initiators will have been fired prior to flight of the spacecraft. It should be noted here that the quantities required for "verification tests" have been deducted from the total manufactured devices and initiators. It seems reasonable that these tests, if performed, should be included in the totals since every initiator and device is serialized and complete traceability required; thus there can be no "behind-the-scenes" tests of production items. If all tests indicated are considered then the total fired rises to 72.5 percent of the manufactured initiators. These figures do not include tests of systems and sub-systems at prime manufacturer facilities; they would also be included if performed.

The single-lot technique can be used to cover more than one flight, provided that the storage life of the devices is not exceeded. This, as in Project Gemini, will result in progressive buildup of demonstrated reliability and confidence. On the other hand, should each vendor of pyrotechnic devices use different initiators, the confidence and reliability demonstration would be based only on the devices themselves and would be considerably less than when using the Standard Initiator concept.

TRACEABILITY AND DATA COLLECTION

To achieve the maximum benefits from the standard initiator concept traceability of all pyrotechnic devices and collection of data from all firings of all devices are essential. The Apollo pyrotechnics program provides for complete and immediate traceability of every initiator manufactured. These records show, by lot and serial number, all shipments of the initiators, their marriages into next higher assemblies (for example, into detonators) and all shipments of these assemblies, with the result that the current location of every initiator is known at all times. Should it be necessary, every initiator and/or device from any given lot can be recalled or set aside for re-examination very rapidly.

The data system will also provide for immediate reporting of data taken during any firing of initiators or pyrotechnic devices. The reported data will be continually analyzed to detect any deviation from specifications, and periodic reports of the demonstrated reliability of the lots can be published. The traceability feature of the system will permit ready determination of compliance with the firing data reporting requirements. Thus the total firing history of any lot can eventually be determined. Further, special analyses of the recorded firing data in off-limit conditions can be made whenever desired.

At present, this data system is being established for the Apollo program only. It will, however, be readily expandable to include all Apollo initiators used by any activity. It appears that an expanded program would be of benefit to all concerned, for the firing and traceability records obtained from each user of the initiator could support all participating activities.

FUTURE PLANS

Several years ago the NASA Manned Spacecraft Center organized a "Pyrotechnics Panel" consisting of representatives of all MSC Project Offices, the research and development divisions, and the organizational elements concerned with safety, preflight and flight operations of manned spacecraft. One goal of this panel is the establishment of the performance and design requirements for a Standard Manned Spacecraft Initiator. Although all the requirements have not yet been formalized, many of the desired features have been incorporated into the Apollo Standard Initiator, which therefore represents an MSC interim-standard device.

Other panel committees are studying other aspects of pyrotechnic devices and systems such as test philosophy, methods, and instrumentation; storage and handling techniques; and identification and traceability methods. The results of panel activities are being incorporated into Project Apollo pyrotechnics insofar as the project schedule permits. The inclusion of the Apollo data collection system into an overall MSC data system for all spacecraft components will probably be accomplished in the relatively near future.

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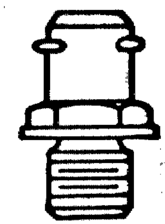
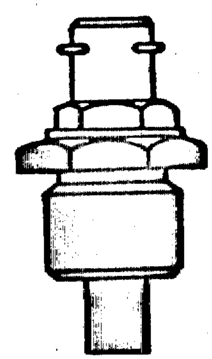


APOLLO STANDARD INITIATOR

- IGNITES PROPELLANTS CHARGES
- FUNCTIONS SMALL PRESSURE DEVICES



APOLLO STANDARD DETONATOR

- DETONATES HIGH EXPLOSIVE CHARGES

NASA-MSC W SIMMONS 4 SEPT 63 S-405-8

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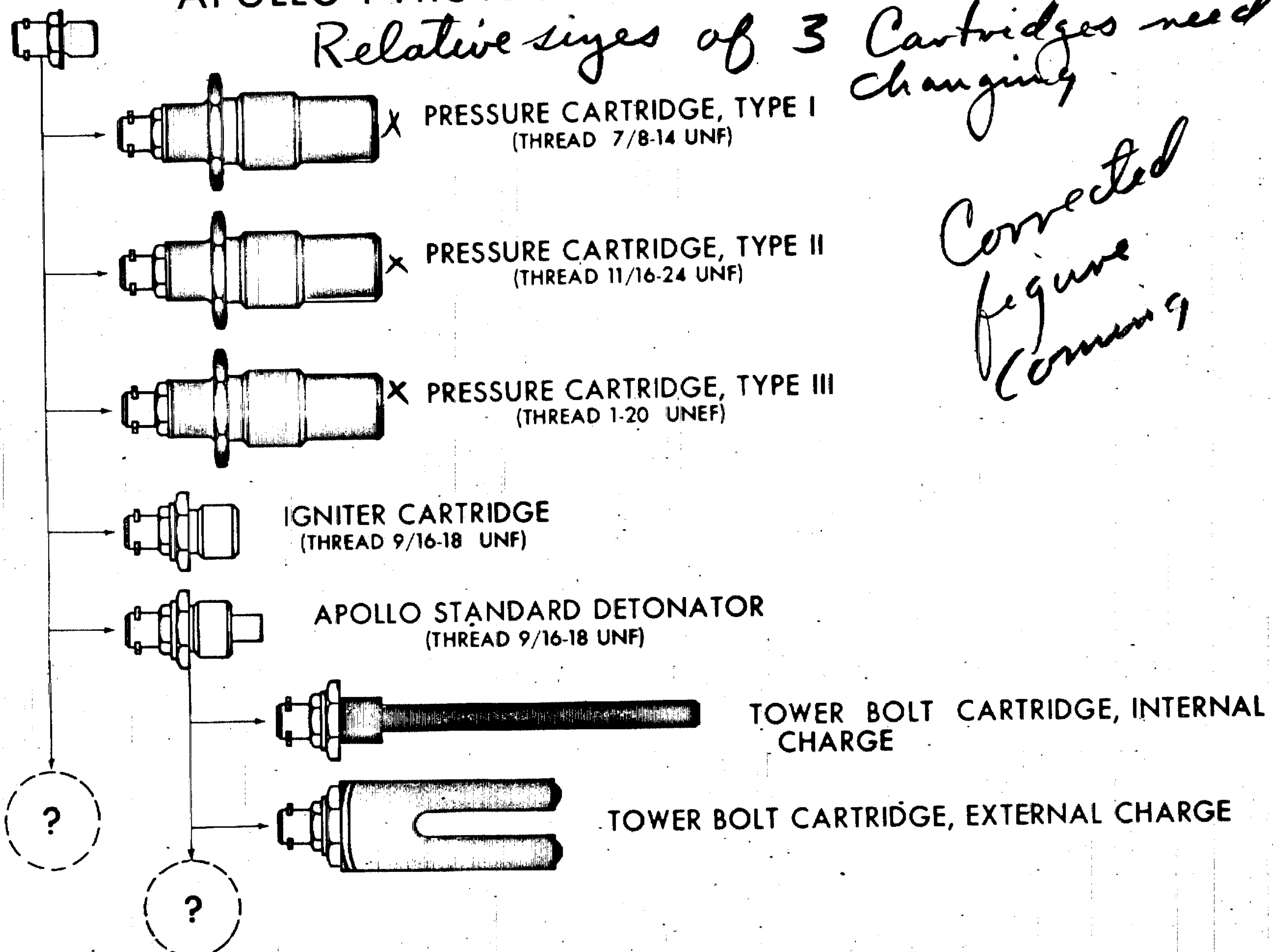
S-63-14896

APOLLO PYROTECHNIC CARTRIDGE FAMILY

Relative sizes of 3 Cartridges need changing

Corrected figure coming



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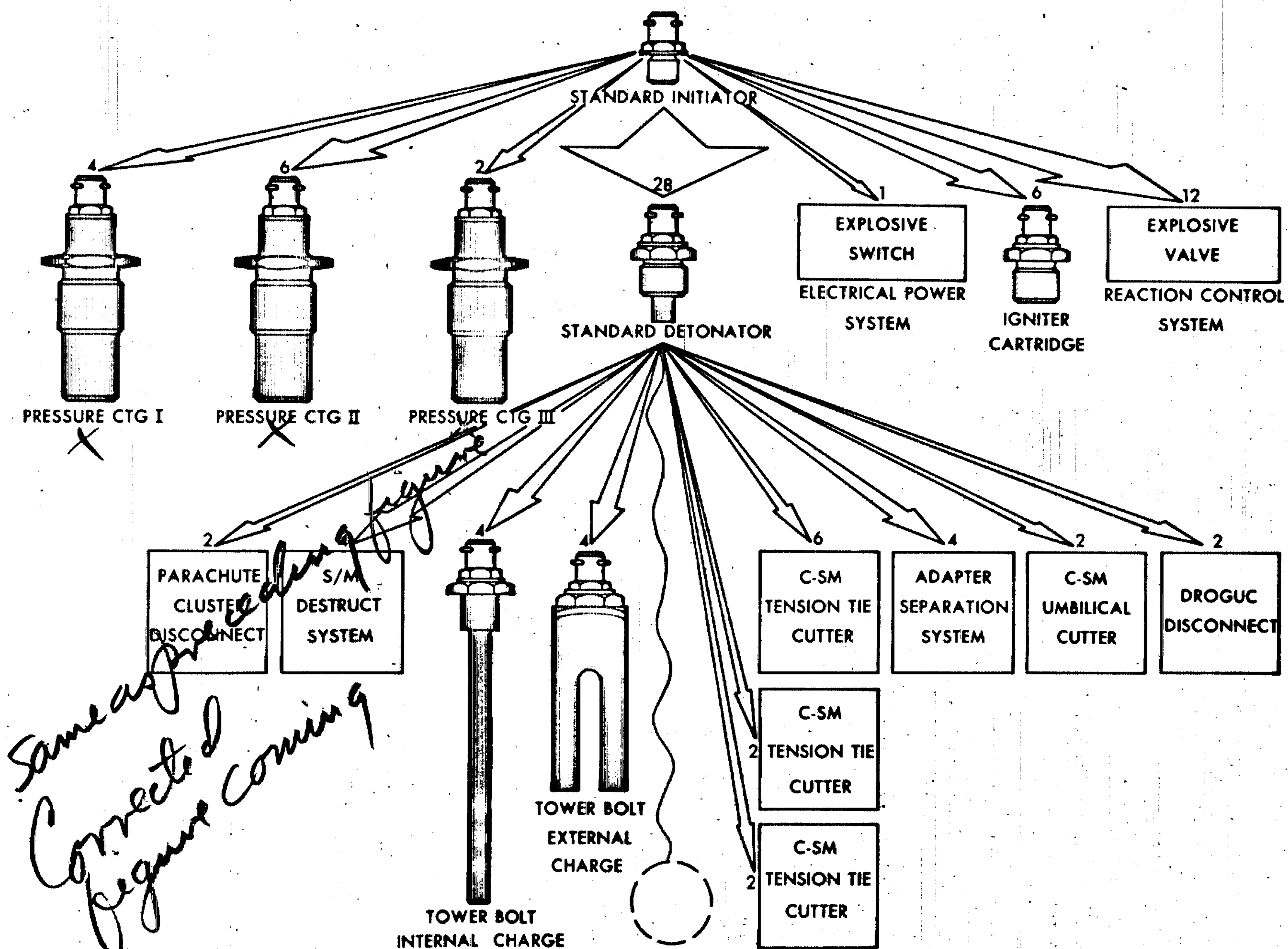
APOLLO PYROTECHNIC FUNCTIONS & DEVICES



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APOLLO INITIATOR ENVIRONMENTS (PARTIAL)

TEMPERATURE	-200 °F TO +300 °F
ACOUSTICS	4.7 TO 9600 CPS 145 TO 168.5 DECIBELS
VIBRATION	COMBINED RANDOM AND SINUSOIDAL 5 TO 2000 CPS
OXIDATION	100% OXYGEN @ 5 PSIA FOR 400 HOURS
VACUUM	7.5×10^{-10} mm Hg

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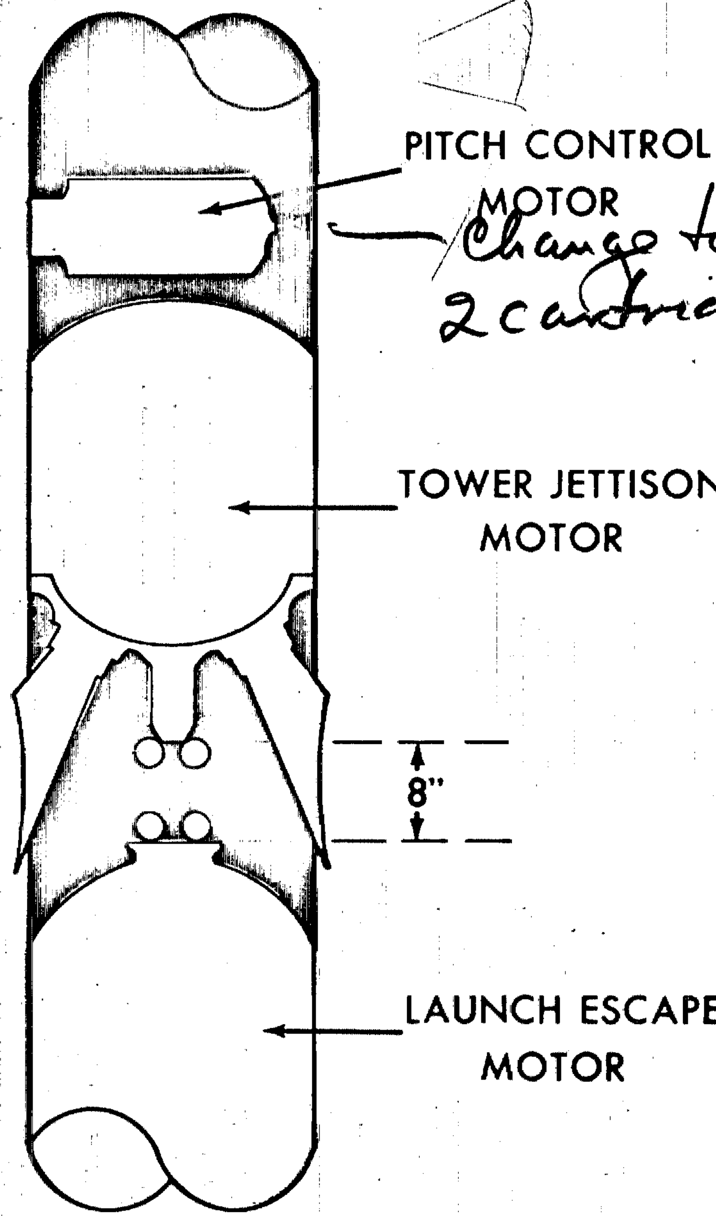
S-63-14893

IGNITER CARTRIDGES

LAUNCH ESCAPE SYSTEM



O IGNITER CARTRIDGES

Corrected figure coming

NASA-MSC W SIMMONS 4 SEPT 63 S-405-3

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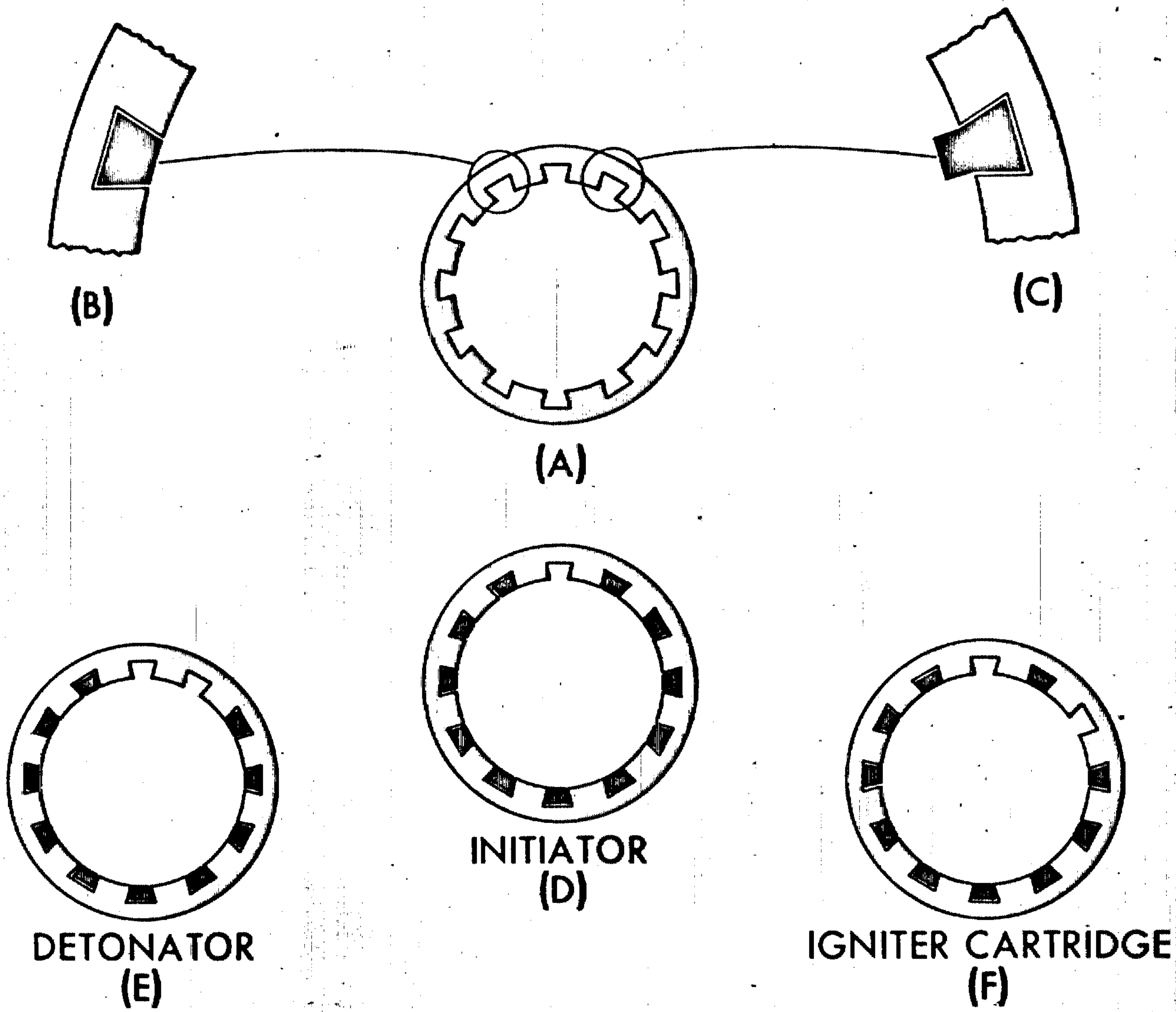
S-63-14894

CONNECTOR INDEXING SYSTEM



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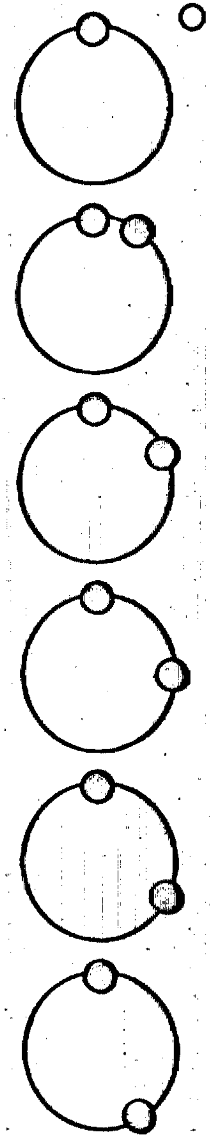
INDEXED FAMILY OF APOLLO PYROTECHNIC CARTRIDGES

A-SCREW TYPE CARTRIDGES



OPEN KEYWAYS

12	APOLLO STANDARD INITIATOR
12 & 1	APOLLO STANDARD DETONATOR
12 & 2	IGNITER CARTRIDGE
12 & 3	PRESSURE CARTRIDGE TYPE I
12 & 4	PRESSURE CARTRIDGE TYPE II
12 & 5	PRESSURE CARTRIDGE TYPE III

NASA-MSC W SIMMONS 4 SEPT 63 S-405-9

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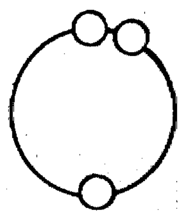
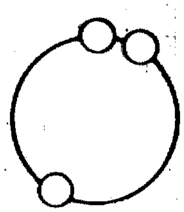
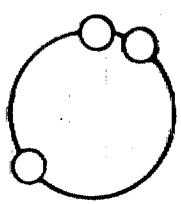
INDEXED FAMILY OF APOLLO PYROTECHNIC CARTRIDGES



12-1-6 CARTRIDGE, TOWER SEPARATION BOLT (INTERNAL CHARGE)



12-1-7 CARTRIDGE, TOWER SEPARATION BOLT (EXTERNAL CHARGE)



12-1-8 CARTRIDGE, DROGUE DISCONNECT

B-CARTRIDGE ASSEMBLIES USING DETONATORS AS INTEGRAL COMPONENTS

NASA
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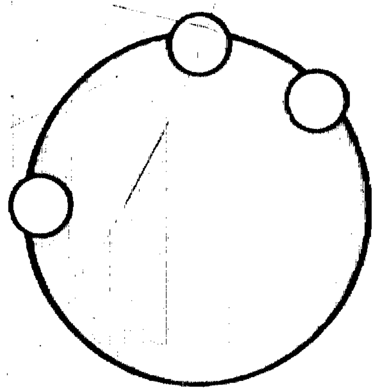
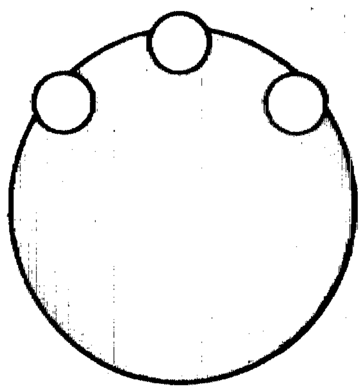
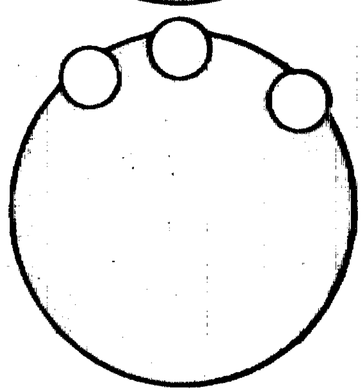
SPECIAL INDEXING OF IGNITER CARTRIDGES

	KEYWAYS OPEN	APPLICATION
	12-2-9	LAUNCH ESCAPE MOTOR
	12-2-10	PITCH CONTROL MOTOR
	12-2-11	TOWER JETTISON MOTOR

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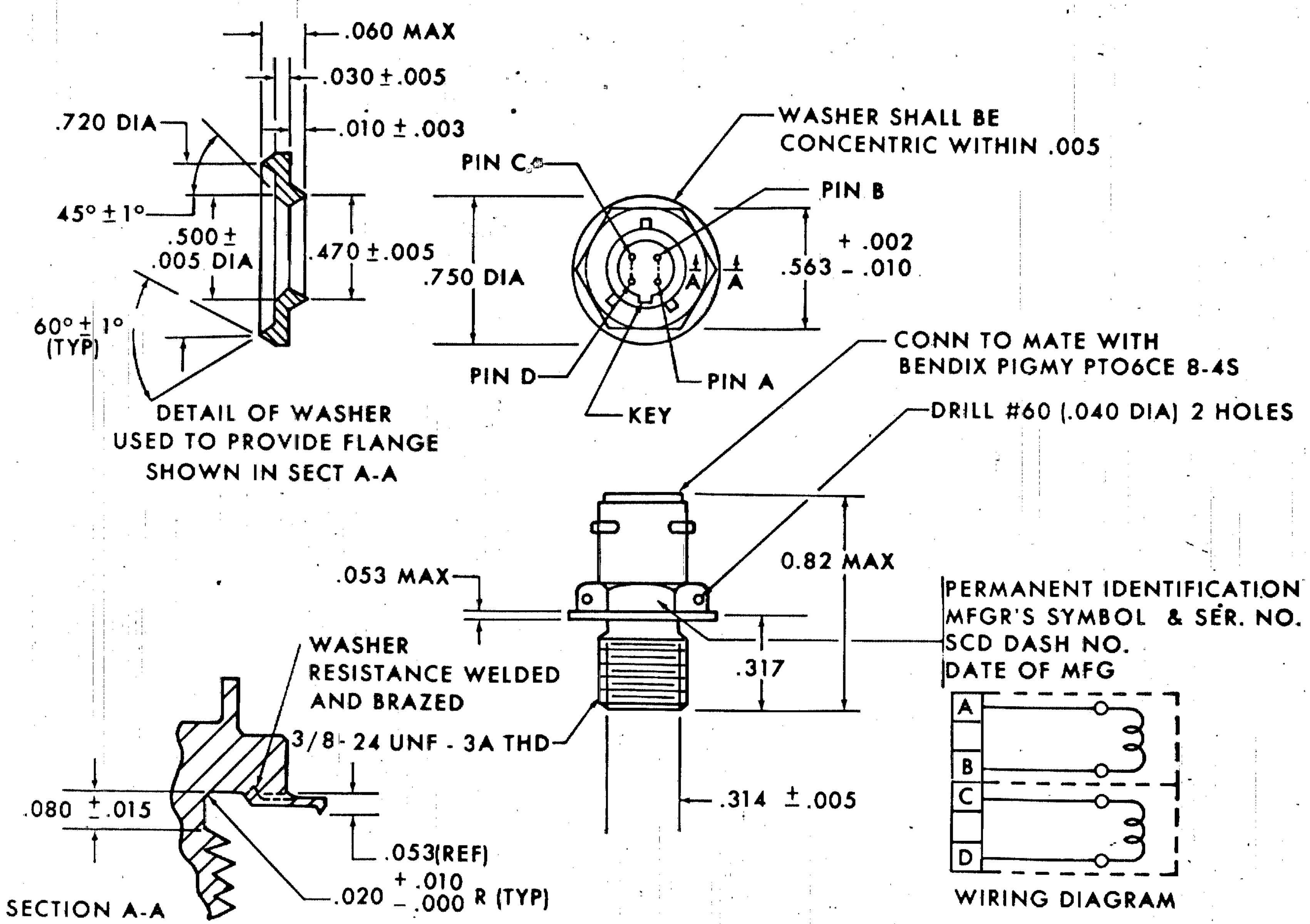
APOLLO STANDARD INITIATOR SPECIFICATION CONTROL DRAWING



NASA-MSC W SIMMONS 4 SEPT 63 S-405-10

NASA
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INITIATORS FIRED FROM ONE FLIGHT LOT PRIOR TO LAUNCH

	LAUNCH SITE						PYRO DEVICE VENDOR				INITIATOR VENDOR		
	FLIGHT ARTICLES	FLIGHT SPARES	SITE TESTS	TOTAL REQUIRED	LOT ACC TEST	LOT VERIFICATION (2) (IF DESIRED)	TOTAL MANUFACTURED	ORDERED (PREVIOUS COLUMN + 10%)	LOT ACC TEST	LOT VERIFICATION (2) (IF DESIRED)	TOTAL MANUFACTURED		
PRESS CTG TYPE I	4	4	8	16	8	4	28 →						
PRESS CTG TYPE II	6	6	12	24	12	6	42 →						
PRESS CTG TYPE III	2	2	4	8	4	2	14 →						
IGNITER CTG	6	6	12	24	12	6	42 →						
BOLT CTG, INTERNAL	4	4	8	16	8	4	28 →						
BOLT CTG, EXTERNAL	4	4	8	16	8	4	28 →						
DROGUE DISCONNECT, CTG	2	2	4	8	4	2	14 →						
DETONATORS, SEPARATE (1)	16	16	32	64	16	8	88	355	39	20	414		
INITIATORS, SEPARATE (1)	13	13	26	52	13	6	71						
MINIMUM FIRED BEFORE FLIGHT			114		85	-42			39	-20		238/352	(3) 67.6%
TOTAL FIRED (INCL VENDOR FIRINGS)			114		85	+42			39	+20		300/414	72.5%

NOTES:

1) DEVICES INSTALLED ON SPACECRAFT AS SEPARATE ITEMS
2) ARBITRARY QUANTITY: ½ OF LOT ACCEPTANCE SAMPLE
3) OMITS LOT VERIFICATION TESTS (62 UNITS)